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Castrucci

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(54) **APPARATUS AND METHOD FOR SEMICONDUCTOR WAFER TEST YIELD ENHANCEMENT**

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(58) **Field of Search** 438/5, 7, 10, 12, 438/13, 14, 795; 700/108, 109, 110, 121; 134/113

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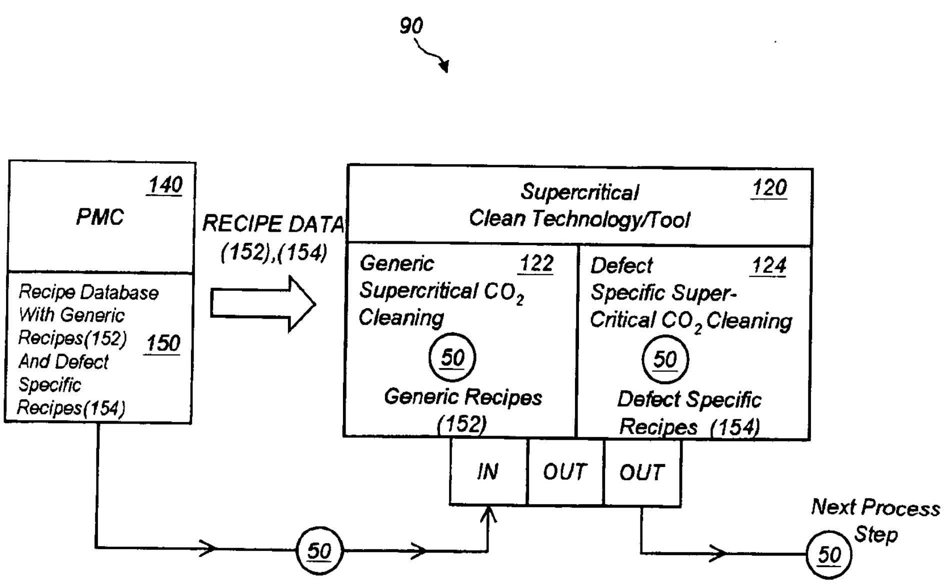
(57) **ABSTRACT**

An improved semiconductor wafer processing system includes defect detection equipment and defect eradication equipment. The defect eradication equipment is a supercritical fluid cleaning apparatus. The defect detection equipment creates a record for each wafer indicating defect identification and characterization results at each wafer processing station. The supercritical fluid cleaning apparatus receives the defect data from the defect detection equipment and applies a defect appropriate supercritical fluid cleaning recipe based on generic cleaning recipes and/or defect specific cleaning recipes. The system further includes equipment for transferring a plurality of semiconductor wafer among a plurality of processing stations under computer control. The improved semiconductor wafer processing system produces IC test yields of the order of 68% and a defect density of 0.1 defects/cm^2 for a 430 mm^2 chip.

36 Claims, 8 Drawing Sheets



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statistical defect data for semiconductor wafer cleaning. After a specific process step, e.g. contact formation, wafer **50** enters the SCF-CT **120** cleaning tool. Recipe data for both generic area **152** and specific defect **154** cleaning appropriate for surface cleaning after the specific process step of the contact formation are transferred to the SCF-CT tool processor. A general supercritical fluid cleaning followed by a specific defect cleaning is applied to wafer **50**. The SCF-CT for generic and defect specific supercritical fluid cleaning may be two separate pieces of equipment or the same piece of equipment equipped with a special configuration to accommodate defect specific cleaning.

Referring to FIG. **6** an apparatus **250** according to the above mentioned embodiment of the ARYES system includes generic SCFT-CT **220**, defect-specific SCFT-CT **230**, a pre-clean chamber **203**, a wafer inspection station **210**, computer controlled cluster tooling **202** for wafer handling, input and output ports **206**, **208**, respectively, process module controller **140**, and recipe database **150**. Curved arrows **205** show schematically the movement of wafers from station to station. Process module controller (PMC) **140** creates process recipes and stores them in database **150**. The PMC **140** can create unlimited number of process recipes, with unlimited number of process steps based on input data from statistical process control software.

Referring to FIGS. **6** and **7**, the following steps are performed during this embodiment of a Yield Enhancement process **400**. Wafers **50** coming to the ARYES system **250** in a pod of wafers **40** are loaded at input port **206** (**402**). Optionally, wafers **50** are processed one by one at a pre-clean station **203** (**404**). Wafers **50** are then transferred to SCFT-CT station **220** and a general supercritical fluid cleaning takes place utilizing generic recipes **152** (**406**). Recipe database **150** stores and provides the generic recipe data **152** to the SCFT-CT processor. Wafers **50** are then routed to defect specific SCFT-CT **230** (**408**) where defect specific cleaning takes place utilizing defect specific recipes **154**. Recipe database **150** also stores and provides the specific defect recipe data **154** to the SCFT-CT processor. The wafers **50** are then optionally directed through another area cleaning process (**410**). Finally wafers **50** pass through an inspection station (**412**) and outputted at output station **208** (**414**).

Referring to FIG. **8**, a typical semiconductor process for IC fabrication contains over 150 individual steps **S1**, **S2**, **S3** . . . SN and requires many weeks to complete. Each one of these steps can generate particulates, film deposits, dust and other contaminants which can result in producing "killer" defects that can impact the IC electrical test yield. Several of the more susceptible process steps include among others, multiple resist strips, multiple chemical mechanical polishing (CMP) steps, multiple interlevel dielectric etching steps, formation of vias and or trenches via etching, N-well implantation and P-well implantation. Furthermore the back end of the line processes produce the majority of the wafer process defects. Back end line processes include deposition of metals, insulators, formation of vias, and CMP of these structures. These defects originate primarily from process tooling and chemicals. After each step **S1**, **S2** . . . SN, wafers **50** are placed in the YES system **100** for defect characterization **110** and surface cleaning via the SCF-CT **120**. The use of SCCO2 cleaning technology adapted to specific cleaning recipes removes these different type of defects and substantially increases the IC test yields.

In one example, in a 430 mm^2 chip we observed a decrease in defect density from 1.0 defect/cm^2 to 0.1 defects/cm^2 with the RYES **100** system of this invention. The corresponding test yield increased from 5% for the 1.0 defect/cm^2 defect level to 68% for the 0.1 defects/cm^2 defect level. Similarly for a 520 mm^2 chip we observed a decrease in defect density from 1.0 defects/cm^2 to 0.1 defects/cm^2 and a corresponding test yield increase from 0% to 63%, respectively.

Other embodiments are within the scope of the following claims. For example, the defect detection and characterization system for "stubborn defects" **215** may include an optical microscope, a transmission electron microscope, or an atomic force microscope for defect detection. For performing chemical analysis of the "stubborn defects" system **215** may also include a mass spectrometer, a secondary ion mass spectrometer (SIMS), an optical spectrometer, a Raman spectrometer, an atomic absorption spectrometer (AAS), an Auger spectrometer, or an Extended X-Ray Absorption Fine Structure (EXAFS) spectrometer.

Several embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A semiconductor wafer processing apparatus comprising:

equipment for transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control;

equipment for identifying and characterizing surface defects on each wafer at at least one of said processing stations and for creating a record of said surface defect data for each wafer at said at least one processing station;

equipment for performing supercritical fluid cleaning of said wafers, wherein said equipment for supercritical cleaning is adapted to receive said surface defect data from said record and apply a supercritical fluid cleaning recipe based on said surface defect data; and

equipment for transferring of cleaned wafers to an output station.

2. The apparatus of claim **1** wherein said record of said surface defect data comprises position coordinates, type, density and size of surface defects on each wafer.

3. The apparatus of claim **1** wherein said equipment for identifying and characterizing surface defects on each wafer is an advanced patterned wafer inspection system with an automatic defect classification program.

4. The apparatus of claim **3** wherein said advanced patterned wafer inspection system with an automatic defect classification program is a COMPASS™ system with On-The-Fly Automatic Defect Classification (OTF™-ADC).

5. The apparatus of claim **1** wherein said supercritical fluid cleaning recipe is a generic recipe comprising:

placing said wafers in a pressure chamber;

introducing a gas that undergoes a supercritical transition into said pressure chamber;

setting temperature and pressure in said pressure chamber to produce a supercritical fluid on the surface of said wafer; and

exposing said wafers for a predetermined time to said supercritical fluid.

6. The apparatus of claim **5** wherein said supercritical fluid is carbon dioxide and said temperature and pressure range from 20 to 70° C. and 1050 to 10000 psi, respectively.

7. The apparatus of claim **5** wherein said supercritical fluid is selected from a group consisting of carbon dioxide,

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carbon monoxide, argon, nitrogen, helium, xenon, nitrous oxide, ethane, and propane.

8. The apparatus of claim **1** wherein said supercritical fluid cleaning recipe is a defect specific recipe comprising:

placing said wafers in a pressure chamber;

introducing a gas that undergoes a supercritical transition into said pressure chamber;

setting temperature and pressure in said pressure chamber to produce a supercritical fluid on the surface of said wafers;

introducing a defect specific co-solvent into said pressure chamber creating a mixture of supercritical fluid with said defect specific co-solvent; and

exposing said wafers for a predetermined time to said mixture.

9. The apparatus of claim **8** wherein said defect specific co-solvent is selected from the group consisting of methanol, isopropyl alcohol and other related alcohols, butylene carbonate, propylene carbonate and related carbonates, ethylene glycol and related glycols, ozone, hydrogen fluoride and related fluorides, ammonium hydroxide and related hydroxides, citric acid and related acids and mixtures thereof.

10. The apparatus of claim **8** wherein a volume ratio of said defect specific co-solvent to the supercritical fluid is within the range of 0.001 to 15 percent.

11. The apparatus of claim **1** further comprising:

equipment for identifying and locating specific stubborn defects with respect to their position coordinates and for updating said data records for any surface cleaned wafer.

12. The apparatus of claim **11** wherein said equipment for locating specific stubborn defects is selected from a group consisting of a scanning electron microscope, an optical microscope, and an atomic force microscope.

13. The apparatus of claim **11** further comprising:

equipment for performing an elemental chemical analysis of said specific stubborn defects.

14. The apparatus of claim **13** wherein said equipment for performing a chemical analysis is selected from a group consisting of a mass spectrometer, a secondary ion mass spectrometer, a Raman spectrometer, an optical spectrometer, and an Auger spectrometer.

15. The apparatus of claim **1** further comprising:

a database storing supercritical fluid cleaning recipe data.

16. The apparatus of claim **15** wherein said supercritical fluid cleaning recipe data comprise generic and defect specific recipes.

17. A semiconductor wafer processing apparatus comprising:

equipment for transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control;

equipment for identifying and characterizing surface defects on each wafer at at least one of said processing stations and for creating a record of said surface defect data for each wafer at said at least one processing station;

equipment for performing supercritical fluid cleaning of said wafers, wherein said equipment for performing supercritical fluid cleaning is adapted to receive said surface defect data from said record and apply a supercritical fluid cleaning recipe based on said surface defect data;

equipment for identifying and locating specific stubborn defects with respect to their position coordinates and for updating said surface defect data records for any surface cleaned wafers;

equipment for performing an elemental chemical analysis of said specific stubborn defects and for updating said surface defect data records for any surface cleaned wafers;

equipment for performing a defect specific supercritical cleaning of said wafers to eradicate said specific stubborn defects wherein said equipment for defect specific supercritical cleaning is adapted to receive said updated surface defect data from said record and apply a defect specific supercritical fluid cleaning recipe; and

equipment for transferring of cleaned wafers to an output station.

18. A semiconductor wafer processing apparatus comprising:

equipment for transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control;

a database storing supercritical fluid cleaning recipe data for at least one of said processing stations; and

equipment for performing supercritical fluid cleaning of said wafers at said at least one processing station, wherein said equipment for supercritical cleaning is adapted to receive supercritical fluid cleaning recipe data based on surface defect data for said at least one processing station from said database.

19. A method for semiconductor wafer processing comprising:

transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control in a predetermined sequence starting at an input station and ending at an output station;

identifying and characterizing surface defects on each wafer at at least one of said processing stations and creating a record of said surface defect data for each wafer at said at least one processing station;

transferring said surface defect data to a supercritical fluid cleaning apparatus;

transferring said wafers to said supercritical fluid cleaning apparatus;

performing supercritical fluid cleaning of said wafers, wherein said supercritical fluid cleaning apparatus is adapted to apply a supercritical fluid cleaning recipe based on said surface defect data; and

transferring of cleaned wafers to an output station.

20. The method of claim **19** wherein said surface defect identification and characterization data comprise position coordinates, type, density and size of surface defects on each wafer.

21. The method of claim **19** wherein said identifying and characterizing of surface defects on each wafer is performed by an advanced patterned wafer inspection system with an automatic defect classification program.

22. The method of claim **21** wherein said advanced patterned wafer inspection system with an automatic defect classification program is a COMPASS™ system with On-The-Fly Automatic Defect Classification (OTF™-ADC).

23. The method of claim **19** wherein said supercritical fluid cleaning recipe is a generic recipe comprising:

placing said wafers in a pressure chamber;

introducing a gas that undergoes a supercritical transition into said pressure chamber;

setting temperature and pressure condition in said pressure chamber to produce a supercritical fluid on the surface of said wafer; and

Effective January 1, 1994, a registered attorney or agent of record may sign a terminal disclaimer. A terminal disclaimer signed by the assignee must fully comply with 37 CFR 3.73(b).

4. Claims 47-51 are rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1, 9, 17-20, 27, 30 and 38 of U.S. Patent No. **6,236,104** and claims 1, 7 and 40-42 of U.S. Patent No. **6,342,725**. Although the conflicting claims are not identical, they are not patentably distinct from each other because all limitations of the present claims have been recited by the patents including:

a single crystal silicon device layer in which there is a predominant intrinsic point defect which is substantially free of agglomerated vacancy-type defects;

a single crystal silicon handle wafer; and,

an insulating layer between the device layer and the handle wafer.

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

5. Claims 47-51 are rejected under 35 U.S.C. 103(a) as being unpatentable over Nakato et al. (U.S. Patent No. 5,436,175) of record, in view of Horai et al. (JP. Patent No. 08-330316).

Nakato teaches a silicon on insulator structure substantially similar as claimed including:

a single crystal silicon device layer (12);

a single crystal silicon handle wafer (14); and,

exposing said wafers for a predetermined time to said supercritical fluid.

24. The method of claim 23 wherein said supercritical fluid is carbon dioxide and said temperature and pressure range from 20 to 70° C. and 1050 to 10000 psi, respectively.

25. The method of claim 23 wherein said supercritical fluid is selected from a group consisting of carbon dioxide, carbon monoxide, argon, nitrogen, helium, xenon, nitrous oxide, ethane, and propane.

26. The method of claim 19 wherein said supercritical fluid cleaning recipe is a defect specific recipe comprising:

placing said wafers in a pressure chamber;

introducing a gas that undergoes a supercritical transition into said pressure chamber;

setting temperature and pressure in said pressure chamber to produce a supercritical fluid on the surface of said wafers;

introducing a defect specific co-solvent into said pressure chamber creating a mixture of supercritical fluid with said defect specific co-solvent; and

exposing said wafers for a predetermined time to said mixture.

27. The method of claim 26 wherein said defect specific co-solvent is selected from the group consisting of methanol, isopropyl alcohol and other related alcohols, butylene carbonate, propylene carbonate and related carbonates, ethylene glycol and related glycols, ozone, hydrogen fluoride and related fluorides, ammonium hydroxide and related hydroxides, citric acid and related acids and mixtures thereof.

28. The method of claim 26 wherein a volume ratio of said defect specific co-solvent to the supercritical fluid is within the range of 0.001 to 15 percent.

29. The method of claim 19 further comprising:

identifying and locating specific stubborn defects on each wafer with respect to their position coordinates and updating said surface defect data record for any surface cleaned wafer.

30. The method of claim 29 wherein said identifying and locating of specific stubborn defects is performed by equipment selected from a group consisting of a scanning electron microscope, an optical microscope, and an atomic force microscope.

31. The method of claim 29 further comprising:

performing an elemental chemical analysis of said specific stubborn defects.

32. The method of claim 31 wherein said chemical analysis is performed by equipment selected from a group consisting of a mass spectrometer, a secondary ion mass spectrometer, a Raman spectrometer, an optical spectrometer, and an Auger spectrometer.

33. The method of claim 19 further comprising:

storing supercritical fluid cleaning recipe data in a database.

34. The method of claim 33 wherein said supercritical fluid cleaning recipe data comprise generic and defect specific supercritical cleaning recipes.

35. A semiconductor wafer processing method comprising:

transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control in a predetermined sequence starting at an input station and ending at an output station;

identifying and characterizing surface defects on each wafer at at least one of said processing stations and creating a record of said surface defect data for each wafer at said at least one processing station;

transferring said surface defect data to a supercritical fluid cleaning apparatus;

transferring said wafers to said supercritical fluid cleaning apparatus;

performing supercritical fluid cleaning of said wafers, wherein said supercritical fluid cleaning apparatus is adapted to apply a supercritical fluid cleaning recipe based on said surface defect data;

identifying and locating specific stubborn defects with respect to their position coordinates and updating said surface defect data records for any surface cleaned wafers;

performing an elemental chemical analysis of said specific stubborn defects and updating said surface defect data records for any surface cleaned wafers;

transferring said updated surface defect data to said supercritical fluid cleaning apparatus;

performing a defect specific supercritical cleaning of said wafers to eradicate said specific stubborn defects wherein said supercritical fluid cleaning apparatus is adapted to apply a defect specific supercritical fluid cleaning recipe based on said updated surface defect data; and

transferring of cleaned wafers to an output station.

36. A semiconductor wafer processing method comprising:

transferring a plurality of semiconductor wafers among a plurality of processing stations under computer control;

storing supercritical fluid cleaning recipe data for at least one of said processing stations in a database;

transferring a supercritical fluid cleaning recipe from said database to a supercritical fluid cleaning apparatus;

transferring said wafers to said supercritical fluid cleaning apparatus; and

performing supercritical fluid cleaning of said wafers, wherein said supercritical fluid cleaning apparatus is adapted to apply said supercritical fluid cleaning recipe based on surface defect data.

* * * * *

including CF_4, CHF_3, CCl_4 and C_2F_6, with an additive to silane mole ratio between 0.3 and 5,and ethylene C_2H_4 and propylene C_3H_6 with an additive to silane mole ratio between 3 and 20.

3. The method according to claim 1 wherein said reaction occurs under the following conditions: a temperature of said substrate is between about 400°C and 650°C, a process pressure is between 1 and 5 millitorr, a frequency of energy in said reactor chamber to produce said plasma is between about 400 KHz and 450 KHz, said plasma has a plasma density in the range of between about 1xE11 and 1xE12 ion/cm^3, said silicon source is silane with a flow of between 100 and 200 sccm, said oxygen source has a flow rate of between 250 and 350 sccm, said carrier gas has a flow of between 50 and 100 sccm, and said gas additive comprises one of the group including CF_4, CHF_3, CCl_4, and C_2F_6 with an additive to silane mole ratio of between 0.5 and 2.5, and ethylene C_2H_4 and propylene C_3H_6 with an additive to silane mole ratio between 5 and 15.

4. The method according to claim 1 wherein said silicon source is an inorganic silane derivative.

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5. The method according to claim 1 wherein said reaction occurs under the following conditions: a temperature of said substrate is between about 250°C and 650°C; a process pressure is between 0.5 and 10 millitorr, frequency of energy in said reactor chamber to produce said plasma is between about 300 KHz and 600 KHz, said plasma has a plasma density in the range of between about 1xE11 and 1xE13 ion/cm^3, said silicon source is an inorganic silane derivatives with a flow of between 50 and 500 sccm, said oxygen source has a flow rate of between 100 and 400 sccm, said carrier gas has a flow of between 20 and 400 sccm, and said gas additive comprises